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SOME EFFECTS OF ENVIRONMENT ON THE GROWTH OF LYMNÆA COLUMELLA Say.[1]

BY HAROLD SELLERS COLTON.

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I. INTRODUCTION.

It is a widely recognized fact that animals raised in confinement differ in various ways from those in the wild state. The differences that are most easily observed are those of relative rate of growth and of relative fertility. Although naturalists for many years have recorded cases of this sort, few have undertaken an experimental study of the factors concerned.

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[1] The writer takes great pleasure in thanking Dr. J. Percy Moore and Dr. E. G. Conklin in particular for many helpful suggestions and criticisms in carrying out the work.

External conditions modifying one structure of an organism have usually been found to be correlated with similar modifications in other organs, yet few correlations between dissimilar physiological processes have ever been observed, although most naturalists hold 'them to be present.

In studying the effect of confinement on organisms, nearly all investigators have chosen the Pond Snail as an animal admirably adapted to their purpose. Perhaps it is largely due to the abundance, to the hardiness, to the rapidity of growth and above all to the extreme sensibility of Pond Snails to any slight change in environment that they have been so universally chosen.

II. Historical.

Jebez Hogg ('54) discovered that *Lymnœa* confined in small aquaria were much smaller than their brothers of the same egg case raised in a large one. The latter were full grown and had produced young which were as large as the former at the end of six months. Hogg attempted to explain this phenomenon by saying that the snail had the power of "adapting itself to the necessities of its existence."

Carl Semper ('79) did not consider this as an explanation. He believed that there was a definite factor that would cause dwarfing. This led him to perform a series of experiments with various sized containers. The conclusion that he arrived at was as follows: that there was a chemical in the water (he had the water analyzed, but nothing was discovered) that stimulates growth without actually contributing to it, but yet is essential, "like oil to a steam engine."

The next investigator to enter this field was E. Yung ('78, '85). He proceeded to raise tadpoles from the egg in various sized and shaped containers. He found that those with the greatest area exposed to the air held the largest tadpoles after a certain length of time. The obvious conclusion was that the dwarfing was caused by lack of aeration.

Stimulated by the experiments of Semper and Yung, De Varigny ('94) made an attempt to solve the problem by returning to *Lymnœa.* After a hundred or more very careful experiments, he did not dare venture any very definite conclusion, but thought that the dwarfing of these Pond Snails was caused by lack of exercise.

Both Semper and De Varigny, on *à priori* grounds, assumed that the manner of respiration in the fresh water pulmonates was entirely performed by the so-called lung. This caused them to overlook the factor of the aeration of the water.

Willem ('96) called attention to this fact and conducted a series of experiments with this particular end in view. Various authors had already noticed that *Lymnœa* in deep lakes never came to the surface, and that under certain conditions they could be made to visit the surface very seldom. Acting on these suggestions, he performed his experiments by running a stream of air bubbles through the water, using De Varigny's experiments as a basis. By this means he was able to explain all of De Varigny's results as due to the simple factor of aeration of the water.

Parallel to the experiments of De Varigny ('94) and Willem ('96), Vernon ('95) experimented at Naples on the growth of Echinoderm larvæ. His conclusions were that dwarfing in confined spaces was due to the concentration of excretory secretions in the medium. Aeration seemed not to be a factor in the growth of Echinoderm larvæ, except for the fact that æration would tend to oxidize the waste products of metabolism.

Warren ('00), as a result of experiments with *Daphnia* in confined spaces, reported that the individuals were dwarfed by the accumulation of their own excretory secretions. This was specific and did not affect the growth and abundance of other crustaceans.

It will be seen that five factors have been advanced to explain dwarfing in confined spaces. These are lack of oxygen, presence of secretions, lack of exercise, presence of unknown chemical, and the adaption to the necessities of existence.

In commenting on these explanations Davenport ('99) writes, "There is, however, much reason for believing that Hogg's conclusion is the one which with our fuller knowledge we can hardly improve upon." In the mind of the author Hogg's explanation is not an explanation but a statement of the fact that confined spaces do affect growth. It does not help us to understand how and why animals adapt themselves to their surroundings.

III. Materials.

After a few preliminary experiments with *Lymnœa, Physa* and *Planorbis,* it was soon found that the former was by far the best form for experiments in the laboratory. There are several reasons for this. *Lymnœa* is abundant in the ponds and streams about Philadelphia. It is not quite as abundant, perhaps, as is *Physa*; yet, except when the ponds are frozen in the winter, is easily procured. A fact of the greatest importance is that eggs are laid throughout the winter, and that these eggs ordinarily develop with slight mortality. The *Lymnœa* on which the following experiments were performed was identified by Dr. H. A. Pilsbry as *Lymnœa columella* Say. This is the most common *Lymnœa* in the neighborhood of Philadelphia. The specimens were procured in certain ponds in Fairmount Park, in a stream near Bryn Mawr, and in the Vivarium of the University of Pennsylvania; the latter had come from an unknown source.

The number of eggs laid at one time by *Lymnœa columella* may vary between one egg and ninety. The egg is, as in the case of other Basiommatophora, imbedded in an albuminous food material, all of which is enclosed by a membrane. This membrane is in turn imbedded in a slimy jelly in which lie the other eggs, laid at the same time. This slimy jelly is again surrounded by an outer layer of jelly, which is quite tough when compared to that matrix which holds the eggs. This tough jelly is thick on the free side, but thin where it cements the eggs to the substratum. In the act of hatching the young snail, which crawls around inside of the membrane, finds its way into the soft jelly mass. After spending a day or two eating this substance, it finally ruptures the wall of tough jelly and escapes. In this jelly mass the eggs are usually placed in three rows. Although the number of eggs may vary greatly, yet in the winter time the average number is about twenty. When adult snails, as soon as the ice is off the ponds in the spring, are brought into the laboratory, they lay the largest number of eggs in a capsule. This fact will be discussed later.

To shed some light on the behavior of the snail after hatching, an egg case containing four young was placed in a dish of water and the positions of the snails after hatching plotted at intervals of five minutes for a period of forty-four hours. From the data gathered in this manner the following generalizations were made:—

1. Although on hatching the lung contained no air, yet 95 minutes, 50 minutes, 110 minutes and 60 minutes respectively were consumed by the different snails in reaching the surface of the water. One snail captured an air bubble before it left the egg case.

2. The movements of snails, previous to their reaching the surface, were more or less at random, and they paid very little attention to the direction of the diffused light in which the experiment was started. However, on first reaching the edge of the dish they, in every case, crawled up to the surface. The snail that captured the air bubble

wandered for 110 minutes after leaving the capsule and then reached the surface by a different method. Letting go from its substratum this snail floated up and proceeded to crawl on the surface film, precisely like an adult snail.

3. In this experiment the snails without exception rested at night. The lack of activity may be due to slightly cooler water, yet the dish was kept in a warm room all of the time. Although these snails had no experience of the oustide world, yet they acted, as far as this experiment indicates, exactly as adults.

Walter ('06) has given us the most complete account of the bionomics of *Lymnœa.* Using his work as a basis it is necessary to call to mind certain activities of the animal. *Lymnœa* has four methods of locomotion, which may be roughly described as gliding, hunching, dangling and dropping. The last two methods are rare and it is not necessary to consider them in this place. The first method is the most common. It consists in the cilia of the foot beating on a path of mucus secreted by the animal and attached to the substratum. When the snail is out of water, when its supply of mucus is inadequate and when certain stimuli are applied the snail resorts to the hunching method, which consists of muscular movements of the foot which bring the snail forward. This is something like the movements of a measuring worm. Whatever method the snail uses it is attached to some substratum, whether it be the sides of the aquarium or the surface film of the water, or suspended by a string of mucus from the surface film or anchored by a string of mucus from the bottom. In these ways the snail can browse on water plants, on the sides of the aquarium, and gather the algæ floating on the surface (Plankton fishing of Brockmeier, '98); but cannot gather any amount of food suspended in the water.

We have seen by the experiments of Hogg, Semper and De Varigny that certain external conditions will inhibit growth in *Lymnœa.* It is interesting to know just what structural differences exist between the full-grown snail, the dwarf and a normal growing snail the size of the dwarf. Hogg ('54) noticed that the dwarfed snail had many characteristics of the newly hatched individual.

A comparison of the structure of a dwarf with a young snail of equal size that was being raised under favorable conditions, and a comparison of the structure of a dwarf with a snail of the same age that had spent its growing period under favorable conditions and therefore much larger, will show certain relations. These relations are as follows:

1. Of snails the same size but not the same age the number of whorls of the shell are the same.

2. The same relation holds true with regard to the arrangement of the viscera, *i.e.*, lobes of the liver, stomach and intestines.

3. Cytologically, however, the tissues of the young snail are quite different from the older ones. As an instance of this the liver of the young snail contains large cells laden with yolk, all of which has been completely absorbed in the dwarf.

In a pond near Geneva Brot[2] found that *Lymnœa* had a malformation on the columella that seemed to be correlated with the presence of *Hydra viridis.* If a snail be long dwarfed and later be put under favorable conditions, the shell is often strangely distorted. The pond near Geneva may have nearly dried up and suddenly filled up again. All the snails in the pond would be under unfavorable conditions and dwarfed. The pond filling up would offer ideal conditions and the snails would grow.

Dr. Pilsbry informed the writer that he has noted cases of this sort.

A question of great interest is, will a dwarf put under favorable conditions "grow up"? In *Lymnœa* many experiments seem to show that a dwarf does not cease to grow, but rather ceases to grow fast. If, however, the snail is put under favorable conditions it starts at once to grow faster and may "grow up." However, they seem "delicate" and it is with difficulty that they are raised.

In this section the writer has attempted to outline some of the points that have certain bearings on the experiments to come.

IV. Methods.

In the brief review of the experiments of various authors that has been given, certain controllable factors were shown that would affect in certain ways the growth of animals. Every author on *a priori* grounds has assumed that (1) food supply will influence growth. It was found by Hogg ('54) and by Semper ('74) that (2) the volume of water affected growth. Semper showed that (3) temperature also was a factor that could not be neglected, and that (4) the number of individuals reacted in some manner on one another. Willem ('96) proved that (5) aeration of the water affected the growth of *Lymnœa,* even as Yung ('79) had previously observed for tadpoles. De Varigny considered that a large (6) area on which a snail could crawl was beneficial to growth. The effect of (7) light was recognized by Higgenbottom ('50) and by Yung ('80). Vernon ('95–'99) completed this list by adding to it a factor, (8) the chemical composition of the water.

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[2] Cited from the *Camb. Nat. Hist.*, Mollusks, p. 88.

There are eight variable factors that have been considered to affect the growth processes of aquatic animals. Each factor, however, is not of equal weight, but should be held in mind and controlled, if possible, in an experimental study. Using the topics named above as a basis for study, the general plan of the experiments that follow in the subsequent section will be to keep every other factor constant and vary one alone.

Precautions.—The experiments were carried out principally in battery jars. The size used in the majority of the experiments was 4 inches in diameter by 5 inches high. Other vessels used were 5 x 6 battery jars, 8 x 10 battery jars and 12-inch dishes.

In order to save repetition we will consider here the methods employed in every case. Where this order has been deviated from, it will be mentioned in its place.

(1) Before each experiment the jars were washed out and wiped clean. In the later experiments the jars were washed with oxidizing solution (potassium bichromate in concentrated sulphuric acid) as an extra precaution.

(2) The water used in the experiments was taken from a large aquarium in the University Vivarium which contained fish. This was done to introduce algæ, etc., without the danger of adding young snails with it.

(3) In any one experiment the jars used were similar, the water was taken from the same source, and the same amount of water was used unless stated otherwise. These conditions being fulfilled, the composition of the water, the algæ for food, and the temperature must vary in the same way.

(4) In a given experiment the jars were placed near together and care was taken so that each received an equal amount of light.

(5) Over each was placed a glass plate to prevent evaporation and the escape of the snails. This latter apparently suicidal behavior, as described by Walter, was found often occurring. In many of the cases that have come under observation, this was caused by the vapor condensing on the glass sides of the jar above the water. Up this wet glass the snail crawls, until temperature changes occur that dry the glass. The snail is then dried and killed. Other cases are not so easy to explain.

(6) Just before an egg case was ready to hatch, with a section lifter it was carefully removed from its substratum and isolated in a jar of water. If the eggs are freshly laid it is usually fatal to the embryos to remove them. In some of the earlier experiments, after the young snail has broken through the egg membrane, the jelly mass was divided

up so that each piece contained an equal number of snails and placed at once under the conditions of the experiment. As there was less mortality by letting the young snails escape from the case normally, they were not placed under the conditions of the experiment until a day after they escaped from the egg case.

(7) In those jars in which I have placed water plant I have tried to add pieces of water plant of equal length and foliage.

(8) Where sediment was needed approximately the same amount was added to each jar.

Measurements.—To measure growth several methods have been used. It is possible to measure volume, weight, a lineal dimension of some part, or the number of successively arising homodynamous structures. In the case of the pond snail the lineal dimension of the length of the shell at once suggests itself. To measure this the following apparatus was arranged. A is a compound microscope with about a 7-inch working distance magnifying the object about three times (fig. 1). O is a snail on a thin glass slide that was placed over a piece of paper ruled in millimeters. The snail was placed with the aperture flat on the glass and the shell would be projected on the ruled lines. Millimeters were then read off on the paper and tenths estimated. This is sufficiently accurate where the work is purely qualitative. A Vernier caliper could not be used on account of the delicacy of the shell.

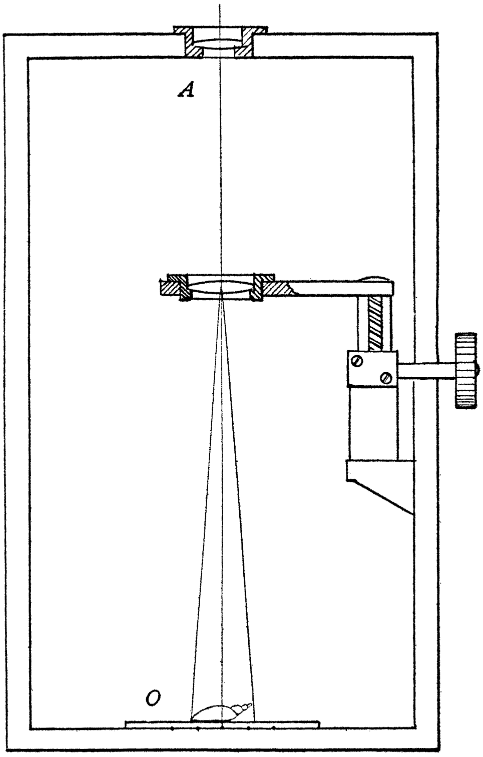

Fig. 1.

In some cases the weight is given. This is not always satisfactory. As growth is a three dimensional phenomenon weight more nearly represents growth. However, the writer found that the snails, large and small, are mathematically similar. That is, the weights are proportional to the cubes of the length.

In determining the average weight all the snails from a given experiment were placed on a microscopic slide of known weight and all excess water wiped away with a clean handkerchief or with lens paper. They were then let dry for three or four minutes and weighed. Dividing the weight found for the snails by the number gives the average.

Tables.—The results of experiments are placed in tabular form. Each experiment consists of two parts; the second member of the pair is in every case the control or the condition most nearly normal. The variable factor precedes it.

A detailed description of the vertical columns of the tables will now be considered. Cf. tables, pp. 421 *et seq.*

Column 1.—The serial number of the experiment.

Column 2.—The number of days the experiment was carried on.

Column 3.—The number of snails placed in a jar at the beginning of the experiment.

Column 4.—The number of snails alive at the time the measurements were taken.

Column 5.—The condition that varied in each pair of experiments.

Column 6.—Certain constant conditions. These constants are in some cases interesting to know. In this column certain abbreviations are used. W P equals Water Plant, *i.e.*, *Myriophyllum*, *Ceratophyllum*, *Elodea* or *Spirogyra*. N indicates no water plant. cc. equals cubic centimeters present in each jar.

Column 7.—Average size. If the number is expressed in ten thousandths, grams are to be implied; if expressed in units and tenths, millimeters.

Column 8.—The differences between pairs are placed opposite the largest number of the pair.

Column 9.—The quantity in this column is the per cent. of the difference to the largest average of the pair. To be able to compare the per cent. difference of the weights with those of lengths the following formula was used, being based on the fact that the snails are similar.

a and b are two members of a pair expressed in grams and $a > b$. Since the shells are similar mathematically, then

$$\frac{\sqrt[3]{a}}{\sqrt[3]{a}-\sqrt[3]{b}} = \frac{100}{X\,\%} \text{ or } X\,\% = 100\,\frac{(\sqrt[3]{a}-\sqrt[3]{b})}{\sqrt[3]{a}}$$

Analysis of Experiments.—To bring the mass of experiments into a form in which they may be more easily considered, a subsidiary table has been compiled from the primary ones. This table consists of four columns (p. 420*a*).

Column 1 contains the number of the primary table for reference.

Column 2 gives the number of experiments in the primary tables that are favorable to the presence of a factor.

Column 3 gives the number of experiments in the primary tables that are favorable to the absence of a factor.

Column 4 shows the number of experiments that are indeterminate. To determine whether an experiment is indeterminate or not certain rules are followed:

1. If there has been a large mortality among the snails which were the larger at the end of the experiment the difference was considered indeterminate. The fact that they were the larger could be explained by the fact that they were the fewer. If, however, the opposite was true, *i.e.*, the mortality was among the smaller snails, then the probability is that they are fewer because the conditions have been the more severe.

2. An experiment has been considered indeterminate if there was a large mortality on both sides of the experiment, notwithstanding the fact that the remaining numbers are nearly equal. The reason for this is the probability that an uncontrolled factor has been acting.

3. When a known factor has acted on one portion of the experiment and not on the other, the difference has been considered indeterminate.

4. Those experiments where the difference is under 10 per cent. of the greatest average has been believed to be indeterminate. This purely arbitrary criterion has been devised to allow for two uncontrollable errors—individual variation and errors in measurement. The obvious way to correct these errors would be to make use of large numbers of individuals in single experiments. As the number of eggs in a case is small, and when the snails are crowded the mortality is large, it has been found impossible to deal with large numbers. A limi of error must be made that will be large enough to cover most unknown errors (see next page).

SECONDARY TABLE.

For description see page 419.

Table			Indeterminate.
I.	Elodea............ 2 exp.	Absence of....... 4 exp.	4 exp.
II.	Myriophyllum..... 6 "	" " ...... 4 "	7 "
III.	Sediment..........13 "	" " ...... 4 "	5 "
IV.	Fæces............. 2 "	" " ...... 0 "	1 "
V.	Flat dish.......... 2 "	Jar and slides.... 2 "	4 "
VI.	" .... 1 "	Battery jar...... 0 "	6 "
VII.	Air bubbles........ 5 "	Absence of...... 2 "	3 "
VIII.	(See Special Table, p. 431)		
IX.	Excretions conc. .. 1[3] "	" "....... 4 "	0 "
	" dilute.. 5 "	" "....... 0 "	0 "
X.	(See Special Table.)		
XI.	Numbers.......... 0 "	" "....... 5 "	0 "
XII.	Shell salts (see Special Table).		
XIII.	Temperature (see Special Table, p. 419).		
XIV.	Cold.............. 0 exp.	Warm...........11 "	1 "
XV.	Dark.............. 0 "	Light............ 5 "	1 "
XVI.	Large area........ 2 "	Small area....... 8 "	9 "
XVII.	Large volume..... 8 "	Small volume... 0 "	3 "
XVIII.	Alternate heat and cold............ 4 "	Warm........... 7 "	4 "
XIX.	Alternate light and dark............ 0 "	Light............ 3 "	2 "
XX.	Alternate starving and feeding...... 0 "	With food........ 5 "	3 "

V. EXPERIMENTS.

1. *Effect of Food.*—Various authors (Semper, Ullyet,[4] Cockerall,[4] Walter, etc.) have shown that *Lymnæa* will eat animal as well as vegetable food. However, the latter furnishes the normal diet. This consists of diatomes, desmids, unicellular and filamentous algæ, the leaves of water plants, and dead leaves of trees. If a snail after hatching is placed in a clean battery jar with 500 cc. of clear pond water that snail will grow, the necessary amount of food being supplied by the microscopic algæ introduced with the water which will increase faster than the snail can eat up. If the temperature is favorable, in the course of two months the snail will reach 7 mm. or 8 mm. in altitude and become sexually mature. The fact that the supply of food keeps ahead of the demand is interesting and led to a series of experiments

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[3] Boiled water from a jar in which a snail had been raised.

[4] Cited from Walter ('06).

with *Myriophyllum* and *Elodea*, to see the effect of these water plants and to discover whether or not their presence is beneficial. *A priori* one would consider that the effect of these larger water plants as *Elodea* or *Myriophyllum* would be beneficial. My experiments seemed in indicate that their effect was the opposite. I at once started a great number of experiments in this line. Some experiments, as can be seen in Table I and Table II, went decidedly one way and some went decidedly the other. The results were chaotic and no generalizations were possible.

A study of the gross anatomy of *Lymnœa* reveals the fact that the anterior portion of the stomach is highly muscular. This muscular sac was originally described by Martin Lister[5] and compared to the stomach of a mullet. Cuvier ('17) more happily compared it to the gizzard of a granivorous bird. It was compared much later by the geologist Whitfield ('82), independently of Cuvier, to the gizzard of a fowl. Whitfield showed that this organ like the gizzard is normally filled with sand in *Lymnœa megasoma.*

Table I—Effect of Elodea.

Ex.	Days.	No. beg.	No. end.	Variable.	Constant.	Size.	Dif.	Per cent.
2A	52	4	3	Elodea.	500 cc.	3.2	—	—
B		4	4	None.		4.0	.8	16%
3A	52	4	2	Elodea.	500 cc.	1.0	—	—
B		4	2	None.		1.6	.6	37%
4A	52	4	4	Elodea.	500 cc.	4.5	—	—
B		4	1	None.		5.0	.5	10%
5A	54	6	5	Elodea.	500 cc.	.0032	—	—
B		6	4	None.		.0220	.0188	50%
6A	54	6	4	Elodea.	500 cc.	.0005	—	—
B		6	4	None.		.0010	.0005	20%
7A	54	6	5	Elodea.	500 cc.	.0010	—	—
B		6	5	None.		.0012	.0002	5%
8A		6	6	Elodea.	500 cc.	.0010	—	—
B		6	5	None.		.0032	.0022	32%
9A		6	5	Elodea.	500 cc.	.0010	.0005	20%
B		6	2	None.		.0005	—	—
10A		6	3	Elodea.	500 cc.	.0016	.0008	23%
B		6	3	None.		.0008	—	—
11A	57	6	6	Elodea.	500 cc.	.0052	—	—
B		6	6	None.		.0077	.0025	12%
12A	57	6	5	Elodea.	500 cc.	.0039	—	—
B		6	6	None.		.0039	—	—

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[5] Cited by Cuvier ('17).

TABLE II—EFFECT OF MYRIOPHYLLUM.

Ex.	Days.	No. beg.	No. end.	Variable.	Constant.	Av. Size.	Dif.	Per cent.
13A	28	2	2	Myrio.	200 cc.	5.0	—	—
B		2	2	None.		5.2	.2	3.8%
14A	50	2	2	Myrio.	400 cc.	9.0	—	—
B		2	2	None.		9.5	.5	5.1%
15A	27	1	1	Myrio.	500 cc.	4.4	.9	20%
B		1	1	None.		3.5	—	—
16A	27	1	1	Myrio.	500 cc.	6.5	1.5	23%
B		1	1	None.		5.0	—	—
17A	48	6	6	Myrio.	460 cc.	3.7	—	—
B		6	6	None.		4.3	.6	14%
18A	48	6	6	Myrio.	680 cc.	3.2	—	—
B		6	5	None.		3.3	.1	3%
19A	48	6	6	Myrio.		1.3	—	—
B		6	6	None.		2.2	.9	41%
20A	69	7	9	Myrio.	400 cc.	3.4	.6	18%
B		7	3	None.		2.8	—	—
21A	69	7	3	Myrio.	680 cc.	5.5	2.0	36%
B		7	4	None.		3.5	—	—
22A	28	2	2	Myrio.	466 cc.	4.4	1.2	27%
B		2	2	None.		3.2	—	—
23A	28	2	1	Myrio.	680 cc.	4.1	—	—
B		2	2	None.		5.1	1.0	20%
24A	29	2	1	Myrio.	2000 cc.	1.7	—	—
B		2	2	None.		2.4	.7	28%
25A	29	2	1	Myrio.	2000 cc.	6.5	—	—
B		2	1	None.		6.5	—	—
122A	37	3	2	Myrio.	500 cc.	4.9	3.2	67%
B		3	2	None.		1.7	—	—
193A	38	4	3	Myrio.	500 cc.	3.9	2.0	51%
B		4	4	Algæ.		1.9	—	—
194A	38	4	4	Myrio.	500 cc.	5.9	3.8	68%
B		4	4	Algæ.		2.1	—	—
195A	38	4	3	Myrio.	500 cc.	8.0	4.6	57%
B		4	4	Algæ.		3.4	—	—

Effect of Sediment.—The gizzard of *Lymnœa columella*, like the latter, is usually filled with fine sand. However, in dissecting a number of individuals of *Lymnœa columella* that had been raised in clean battery jars I found no sign of sand. In a few individuals I found some grains, when a diligent search of the jar failed to reveal any more. It seems that this individual had in its crop the only grains of sediment that the jar contained.

TABLE III—EFFECT OF SEDIMENT.

Ex.	Days.	No. Beg.	No. End.	Variable.	Constant.	Av. Size.	Dif.	Per cent.
85A		2	2	Sediment.	N. 500 cc.	5.1	1.9	37%
B		2	2	None.	"	3.2	—	—
86A		2	1	Sediment.	W. P. 500 cc.	4.1	—	—
B		2	2	None.	"	4.4	.3	6%
87A		2	2	Sediment.	W. P. 500 cc.	5.0	.5	10%
B		2	1	None.	"	4.5	—	—
88A		2	2	Sediment.	W. P. 500 cc.	3.6	—	—
B		2	2	None.	"	4.6	1.0	22%
89A		2	2	Sediment.	N. 200 cc.	6.5	4.1	63%
B		2	2	None.	"	2.4	—	—
90A		1	1	Sediment.	W. P. 200 cc.	6.5	4.4	67%
B		1	1	None.	"	1.7	—	—
118A	60	3	1	Sediment.	N. 500 cc.	8.0	4.4	55%
B		3	3	None.	"	3.6	—	—
119A	60	2	1	Sediment.	N. 500 cc.	7.9	5.7	72%
B		2	2	None.	"	2.2	—	—
120A	60	2	2	Sediment.	N. 500 cc.	7.4	2.0	27%
B		2	2	None.	"	5.4	—	—
121A	60	2	2	Sediment.	N. 500 cc.	8.1	3.1	38%
B		2	2	None.	"	5.0	—	—
124A	43	4	4	Sediment.	N. 500 cc.	1.8	—	—
B		4	4	None.	"	1.9	.1	5%
125A	43	4	4	Sediment.	N. 500 cc.	2.3	1.0	43%
B		4	4	None.	"	1.3	—	—
126A	51	4	4	Sand.	N. 500 cc.	3.4	.8	23%
B		4	4	None.	"	2.6	—	—
127A	51	4	4	Sediment.	N. 500 cc.	2.1	—	—
B		4	4	None.	"	2.6	.5	19%
128A	37	3	3	Myrio.	500 cc.	9.0	3.7	41%
B		3	3	Myrio (washed).	"	5.3	—	—
129A	47	4	4	Ignited sediment.	N. 500 cc.	2.	—	—
B		4	4	None.	"	2.9	.9	31%
130A	47	4	4	Sand.	N. 500 cc.	3.5	.6	17%
B		4	4	None.	"	2.9	—	—
131A	77	3	3	Sediment.	N. 500 cc.	1.7	—	—
B		3	3	None.	"	3.5	1.8	51%
132A	77	3	3	Sand.	N. 500 cc.	4.7	1.2	23%
B		3	3	None.	"	3.5	—	—
133A	77	3	2	Gravel.	N. 500 cc.	6.0	2.5	41%
B		3	3	None.	"	3.5	—	—
123A	38	4	4	Sediment.	N. 500 cc.	2.1	.3	14%
B		4	4	None.	"	1.8	—	—
196A	38	4	4	Sediment.	W. P. 500 cc.	5.9	2.0	34%
B		4	3	None.	"	3.9	—	—

Another point of importance in these experiments was the fact that in no cases was the water plant attacked when sediment was not present. On the other hand, in jars with sediment present the normal thing was to have the leaves of the water plant cut to pieces.

To determine whether the presence or absence of sediment would affect the growth processes of the snail a number of experiments were undertaken. The sediment used in Experiments 85, 86, 87 and 88, was mud from the pond in the Botanic Gardens. This was washed and that which settled in from 1 to 5 minutes kept for experimental purposes. Because this mud would probably introduce food into the jars, soil from the garden bed was taken, boiled and that which settled in from 1 to 5 minutes used in Experiments 89 and 90. In Experiments 118–121 the sediment was boiled in concentrated nitric acid, evaporated to dryness, and ignited. This would surely destroy all organic matter; yet the results of these experiments continued to show the benefit of the sediment. Quartz sand and quartz pebbles washed with nitric acid gave beneficial results also. If the *Myriophyllum* was washed in running water the snails did not grow as large as if it was used with the particles of sediment still clinging to the leaves.

In conclusion it seems probable that (1) the muscular gizzard filled with sand is necessary to break up the plant cells that have been torn off by the radula. (2) The absence of sand seems to have the effect of causing the snails not to rasp off cells from the tissues of water plant. (3) If there is enough small algæ present, *Myriophyllum* will have little or no effect on the growth. (4) An examination of the stomach of small snails under 5 mm. shows that such plant tissue as *Myriophyllum* is not eaten. With snails 5 to 12 mm., however, great gashes are torn in the leaves, and the stomach is filled with the crushed cells. (5) The discordant results of Tables I and II are no doubt due to the presence or absence of sediment.

Fæces.—The amount of fæces produced by *Lymnæa* is enormous and Walter ('06) reports that *Lymnæa elodes* forms cylinders of fæcal matter fourteen times its own length every twenty-four hours. This collects at the bottom of the aquaria in great tangled masses.

De Varigny ('94) investigated the effect of this material on the growing snail. The result of his experiments was the stunting of the snails in the jar with the fæcal masses. In repeating these experiments of De Varigny the writer gathered fæces from a jar in which a snail had been living for a month or two. This matter in some cases was washed in a filter and in others by decanting. This washed material was added to jars of snails. The result indicated in Table IV was the opposite from that found by De Varigny. However, the latter did not wash the fæcal material, and so introduced into the water a large amount of soluble excreted material that he himself found so harmful to the growing snail.

TABLE IV—EFFECT OF FÆCES.

Ex.	Days.	No. Beg.	No. End.	Variable.	Constant.	Av. Size.	Dif.	Per cent.
45A	40	1	1	Fæces.	N.	3.0	1.2	40%
B		1	1	None.		1.8	—	—
46A	60	8	8	Fæces.	N.	3.6	—	—
B		8	6	None.		4.0	.4	10%
47A	54	5	4	Fæces.	N.	7.0	4.0	59%
B		5	3	None.		3.0	—	—

Rathay's ('98) observations on *Helix hortensis* and Young's ('88) observations on *Helix pomatia* and on *Arion* show that these pulmonates eat a great mass of food, very little of which appears to be assimilated or even digested.

Observations of the fæcal matter of *Lymnæa* shows the same thing true for these pond snails. Although the writer did not perform any special tests on the cells found in fæces, as did Rathay ('98), yet the appearance of the *Pleurococcus* and desmids in those masses was so nearly normal that there is very little doubt that there was any change.

Other Effects of Water Plants.—Warren ('00) discovered that *Daphnia* in a vessel filled with *Vallisneria* became less and less productive. If, however, the bulk of the water plant was removed, the crustaceans soon regained their normal number. As green light was found to be unfavorable to the fertility of *Daphnia,* Warren concluded that the mass of green plant caused the light to be green and the *Daphnia* infertile in consequence.

It can be imagined from what has been said that the effect of water plant on the physiological processes of organisms is not simple and it is not easy at once to discover just how it acts.

2. *Aeration.*—This section should be treated under the head of the composition of the water, but as Semper, De Varigny, Willem and Walter have each considered it separately, it was thought best to follow them and make it an independent topic.

On *a priori* grounds Semper ('79) and De Varigny ('94) both decided that the only means of respiration in *Lymnæa* was by the specially differentiated so-called lung; therefore these mollusks must come to the surface for air. However, the observations of v. Siebold[6] ('59), Pauly[6] ('77), Forel ('69, '74, '04), Andre[6] ('01), Walker ('00) and the experiments of Willem ('96) show that the respiration of the animal is in a large part carried on by the outer surface of the body.

De Varigny's Experiment.—De Varigny noticed that dishes with the largest area contained the largest snails. This at once suggested aeration. To determine whether this was the true explanation, he half immersed a small glass cylinder with the bottom covered with muslin in a large vessel of water. To insure the mixture of the water in both vessels, he lifted the small vessel out of the large one daily and allowed it to empty and fill, when he replaced it again. In each vessel he introduced a snail of equal size and age; and at the end of the experiment the one that had a large place in which to roam was the larger. As the water in both compartments was in communication, the amount of oxygen in both vessels must be identical. Therefore, the snail having the greatest area to roam about, on his exercise theory, became the larger.

Willem's Experiment.—Semper ('79) found that to carry air bubbles through a vessel containing young snails created such a disturbance that the small snails were washed from their substratum. Willem ('96) devised an apparatus for conducting air bubbles through a liquid without disturbing the water. It consisted of a glass tube (fig. 2) (*a*) immersed in the jar to be experimented on. Below the surface was blown a hole (*o*). Tube (*c*), turned upon the end, conducted bubbles of air into tube (*a*). The bubbles escaped into the water and travelled up tube (*a*), the water carried up by the bubble escaping by the hole (*o*), and the air bubble continued up the tube and escaped.

Willem repeated the experiment of De Varigny, but introduced his aerating apparatus into the small jar (fig. 3). The water, kept constantly interchanging in the large and small vessel, caused the snails to be of equal size.

Vernon ('03) explained the results of this experiment not by lack of aeration, but by the increase of excretory products which did not pass freely through the muslin.

Surface Aeration.—The experiments undertaken by the writer are considered under two heads—surface aeration and artificial aeration. The effect of surface aeration was determined by the use of flat dishes and a battery jar for control. To make the inside area of the jar equal to the inside area of the dish, so as to have equal areas inside the jar

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[6] Cited from Walter ('06).

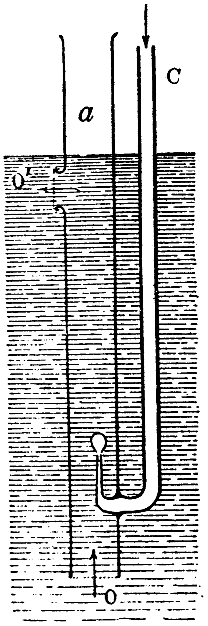

Fig. 2. (After Willem.)

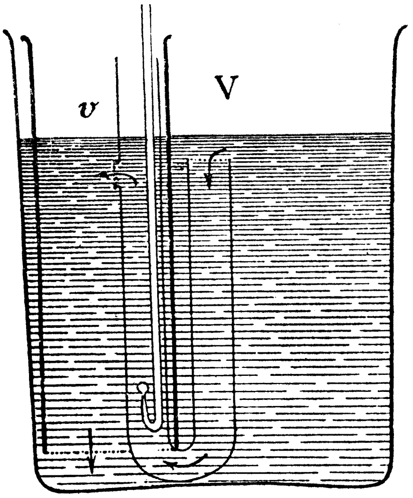

Fig. 3. (After Willem.)

for algæ to grow upon and for the snail to "exercise" upon, a structure of microscopic slides of calculated area was introduced. Table V gives the results of these experiments. These results are seen to have little

Table V—Flat Dish and Jar Area Increased by Slides.

Ex.	Days.	No. Beg.	No. End.	Variable.	Constant.	Av. Size.	Dif.	Per cent.
29A	48	6	6	Large sur. area.	N. 500 cc.	2.2	—	—
B		6	5	Small sur. area.		3.2	1.0	30%
30A	48	6	6	Large sur. area.	W. P. 500 cc.	1.3	—	—
B		6	6	Small sur. area.		3.9	1.6	40%
31A	28	2	2	Large sur. area.	W. P. 500 cc.	4.6	.1	2%
B		2	1	Small sur. area.		4.5	—	—
32A	28	2	2	Large sur. area.	W. P. 500 cc.	3.6	—	—
B		2	2	Small sur. area.		5.	1.4	28%
94A	58	2	2	Large sur. area.	N. 500 cc.	5.7	1.0	18%
B		2	2	Small sur. area.		4.7	—	—
95A	58	2	2	Large sur. area.	N. 500 cc.	6.5	2.1	32%
B		2	2	Small sur. area.		4.4	—	—
96A	51	3	3	Large sur. area.	N. 500 cc.	4.2	—	—
B		3	3	Small sur. area.		4.5	.3	6%
97A	35	2	1	Large sur. area.	N. 500 cc.	7.2	3.0	41%
B		2	2	Small sur. area.		4.2	—	—

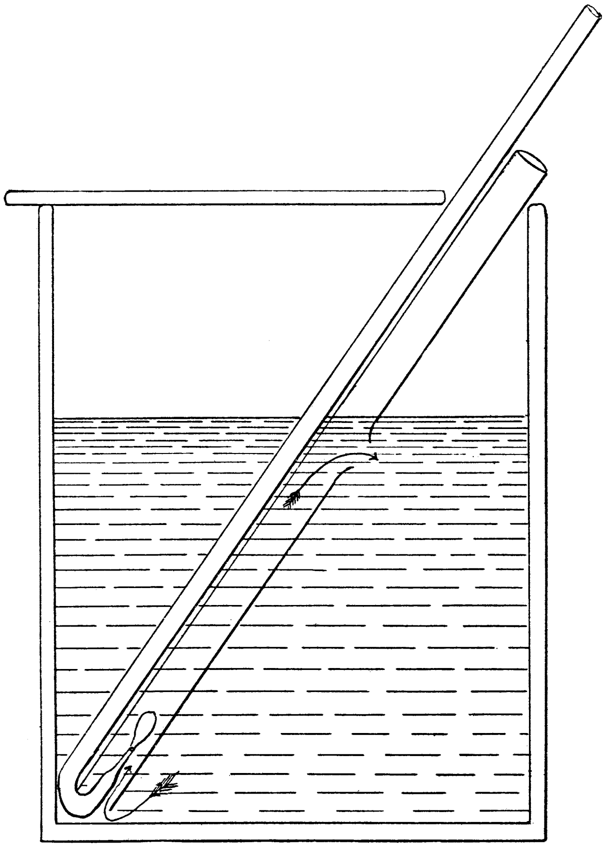

Fig. 4.

significance. In some, however, no slides were used (Table VI). Out of seven experiments but one difference was significant, and that one indicated that the larger surface was beneficial.

However, these experiments seem to indicate that the effect of surface aeration is not very striking, yet increased aeration by the surface of the water no doubt is of slight advantage to the growth of the snail.

Artificial Aeration.—In a number of experiments streams of air bubbles were conducted through jars of water. The apparatus used was a modification of that of Willem ('96) (see fig. 4). In Experiments 37–43 (Table VII) the air was passed through night and day, in the remaining experiments for but eight hours a day. The results confirm Willem's conclusion that cuticular respiration is a large factor in the growth of *Lymnæa.*

TABLE VI—FLAT DISH AND BATTERY JAR.

Ex.	Days.	No. Beg.	No. End.	Variable.	Constant.	Av. Size.	Dif.	Per cent.
33A	28	2	2	Large sur. area.	W. P. 500 cc.	4.6	.2	4%
B		2	2	Small sur. area.		4.4	—	—
34A	28	2	2	Large sur. area.	W. P. 500 cc.	3.6	—	—
B		2	1	Small sur. area.		4.1	.5	12%
98A	58	2	2	Large sur. area.	N. 500 cc.	5.7	1.2	21%
B		2	2	Small sur. area.		4.5	—	—
99A	58	2	2	Large sur. area.	N. 500 cc.	6.5	—	—
B		2	1	Small sur. area.		8.0	1.5	18%
100A	54	4	4	Large sur. area.	N. 500 cc.	3.9	—	—
B		4	3	Small sur. area.		4.2	.3	7%
101A	51	3	3	Large sur. area.	N. 500 cc.	4.2	.2	4%
B		3	3	Small sur. area.		4.0	—	—
102A	35	2	1	Large sur. area.	N. 500 cc.	7.2	2.5	34%
B		2	2	Small sur. area.		4.7	—	—

TABLE VII—ARTIFICIAL AERATION.

Ex.	Days.	No. Beg.	No. End.	Variable.	Constant.	Av. Size.	Dif.	Per cent.
37A	27	1	1	Air bubbles.	N. 500 cc.	3.8	1.0	26%
B		1	1	None.	"	2.8	—	—
38A	42	1	1	Air bubbles.	W. P. 500 cc.	8.8	2.4	27%
B		1	1	None.	"	6.4	—	—
39A	42	1	1	Air bubbles.	W. P. 500 cc.	8.2	.2	2%
B		1	1	None.	"	8.0	—	—
40A	42	1	1	Air bubbles.	N. 500 cc.	7.0	2.5	36%
B		1	1	None.	"	4.5	—	—
41A	52	1	1	Air bubbles.	W. P. 750 cc.	6.2	2.2	36%
B		1	1	None.	"	4.	—	—
42A	52		15	Air bubbles.	W. P. 750 cc.	2.	—	—
B			14	None.	"	2.8	.8	29%
134A	26	4	4	Air bubbles.	W. P. 500 cc.	4.9	—	—
B		4	4	None.	"	5.9	1.0	17%
135A	26	4	3	Air bubbles.	W. P. 500 cc.	3.1	.2	6%
B		4	2	None.	"	2.9	—	—
197A		4	4	Air bubbles.	W. P. 500 cc.	5.8	—	—
B		4	4	None.	"	7.0	1.2	17%
198A		4	4	Air bubbles.	W. P. 500 cc.	6.8	3.	44%
B		4	4	None.	"	3.8	—	—

Walter's ('06) experiments show that *Lymnæa* will live in boiled water, but come to the surface more often. If imprisoned below the surface of aerated water they die.

In consideration of the above the writer believes the following statement of Willem not altogether supported by the facts. Willem ('96) writes, p. 567: "Ces expériences, ..., prouvent que chez les Basommatophores la respiration cutanée est plus importante que la respiration pulmonaire et qu'à elle seule, elle peut suffire à la vie de ces animaux."

3. *The Composition of the Water.*—The present study considers those conditions alone in which the composition of the water might affect the growth of pond snails under natural conditions.

Effect of Accumulation of Excreted Matter.—De Varigny ('94) grew snails in water in which a snail had been living for months, with the result that the snails were dwarfed. Vernon ('95) performed similar experiments with Echinoderm larvæ with the same result. The writer has conducted experiments of this sort on *Lymnæa.* Table IX expresses the results of eight experiments. These results are as follows: (1) That weak solutions of the waste products of metabolism are of benefit to the snail. (2) That concentrated solutions are harmful. (3) In Experiments 136 and 199 the water was aerated so the factor of the aeration of the water would be constant. In Experiment 143 the water was boiled, yet in these two cases the results were similar. Later the experiments of Table X were repeated with different dilutions of urea with similar results. As these were similar to those found by Vernon ('95), who used also uric acid on Echinoderm larvæ, it was not thought necessary to continue the experiments further.

Analyses of the water. A year before Vernon's ('99) paper was called to the attention of the writer, a series of analyses were made of the water in a number of jars. Although not nearly so extensive as those of Vernon, yet the results were nearly parallel.

By the methods of water analysis (Clowes and Coleman, '03), the water in the jars of several experiments was analyzed for chlorides, nitrates and particularly for free and for albuminoid ammonia. The free ammonia consists largely of the inorganic salts of ammonia. Albuminoid ammonia on the other hand is made up of organic compounds from which the ammonia radicle is not detached by boiling with sodium carbonate.

Experiments 200 and 201, Table VIII, were conducted in the following manner: Six jars with 500 cc. of water, which was analyzed before the experiment, were taken. Two were used without water plant or snail as control. The other jars contained snails and water plant as follows: one without water plant but with one full-grown snail, one without water plant but with five snails, one with water

TABLE VIII.

Experiment 200.

Analysis for	Water beginning of experiment. Grams in 1000 cc.	Water at end of experiment. Grams in 1000 cc.	Water at end of experiment. Grams in 1000 cc. 1 snail.	Water at end of experiment. Grams in 1000 cc. 5 snails.
Free NH_3...	.0003	.0012	.0120	.0300
Alb. NH_3...	.0020	.0010	.0012	.0080
Calcium.....	.0100	.0090	.0090	.0100
Chloride	.0080	.0018	.0018	.0020

Experiment 201.

Analysis for	Water beginning of experiment. Grams in 1000 cc.	Water at end of experiment. Grams in 1000 cc.	Water at end of experiment. Grams in 1000 cc. Myriophyllum.	Water at end of experiment. Grams in 1000 cc. Myriophyllum. 2 snails.
Free NH_3...	-0003	.0012	.00025	No trace.
Alb. NH_3...	.0020	.0010	.00018	.0080
Calcium.....	.0100	.0080	.01000	.0100
Chloride	.0080	.0016	.00160	.0020

Experiment 202.

Size of Snail.	Free NH_3. Grms. per 1000 cc.	Alb. NH_3. Grms. per 1000 cc.
Control, no snail present.	.025	.018
2.8 mm.	.015	.025
10 mm.	.075	.030
11.5 mm.	.075	.025
15.5 mm.	.155	.030

plant and no snail, and one with water plant together with two snails. After ten days the water was analyzed. The following facts seem to be illustrated by these experiments: (1) Calcium and chlorides in the water do not seem to be affected by the excretions of the snail. (2) In the jar that contained no snails yet contained *Myriophyllum* nearly all the free ammonia was taken up by the water plant. This is a phenomenon well known to botanists (Sachs, '75 ; Bessy, '92). Vernon ('99) found that the presence of *Ulva* decreased the free ammonia, but increased the albuminoid ammonia.

TABLE IX—EFFECT OF EXCRETIONS.

Ex.	Days.	No. beg.	No. end.	Variable.	Constant.	Av. Size.	Dif.	Per cent.
				Tap. water. Old water.				
142A	40	1	1	300 cc.	N. 100 cc. pond w.	1.8	—	—
B		1	1	200 cc. + 100 cc.		2.7	—	—
C		1	1	100 cc. + 200 cc.		2.4	—	—
D		1	1	300 cc.		1.5	—	—
				Boiled pond wat. Boiled old wat.				
143A		9	6	500 cc. + 0 cc.	+ 100 cc. pond w.	2.6	—	—
B		9	8	450 cc. + 50 cc.	"	3.4	—	—
C		9	9	400 cc. + 100 cc.	"	3.1	—	—
D		9	7	200 cc. + 300 cc.	"	3.3	—	—
E		9	9	0 + 500 cc.	"	3.3	—	—
144A	44	4	3	Dilute old water.	300 cc.	3.4	1.3	40%
B		4	3	Control.	300 cc.	2.1	—	—
145A	44	4	2	Dilute old water.	300 cc.	3.6	1.6	44%
B		4	2	Control.	300cc.	2.0	—	—
146A	26	4	2	Old water.	500 cc.	2.9	—	—
B		4	4	Control.	500 cc.	5.9	3.0	50%
200A		4	4	Old water.	500 cc. W. P.	3.8	—	—
B		4	4	Control.	500 cc.	7.0	3.2	46%
136A	26	4	3	Old water.	W. P. 500 cc.	3.1	—	—
B		4	4	Control.	Aerated.	4.9	1.8	36%
199A	26	4	4	Dilute old water.	W. P. 500 cc.	6.8	1.0	14%
B		4	4	Control.	Aerated.	5.8	—	—

TABLE X—EFFECT OF UREA.

Ex.	Days.	No. beg.	No. end.	Variable.	Constant.	Av. size.
137A	22	1	D	No. urea.	500 cc.	Dead.
B		1	1	$\frac{1}{5000}$ N. urea.	"	2.0
C		1	1	$\frac{1}{2500}$ N. urea.	"	2.6
D		1	1	$\frac{1}{1000}$ N. urea.	"	2.5
E		1	1	$\frac{1}{500}$ N. urea.	"	2.8
F		1	D	$\frac{1}{250}$ N. urea.	"	Dead.
138A	27	1	1	$\frac{1}{100}$ N. urea.	500 cc.	2.8
B		1	1	Control.		3.5
139A	27	1	1	$\frac{1}{100}$ N. urea.	500 cc.	3.8
B		1	1	Control.		5.0
140A	37	4	3	Control.	500 cc.	1.7
B		4	4	$\frac{1}{1000}$ N. urea.	"	1.9
C		4	3	$\frac{1}{500}$ N. urea.	"	1.5
D		4	0	$\frac{1}{100}$ N. urea.	"	Dead.

TABLE XI—EFFECT OF NUMBERS.

Ex.	Days.	No. beg.	No. end.	Variable.	Constant.	Av. Size.	Dif.	Per cent.
60A	52	1	1	The number.	W. P.	4.	1.2	30%
B		17	15	"		2.8	—	—
61A	52	1	1	The number.	W. P.	3.2	.5	16%
B		17	5	"		2.7	—	—
62A	52	1	1	The number.	W. P.	6.2	4.2	70%
B		17	14	"		2.	—	—
203A		40	32	1 in a jar.	W. P. 500 cc.	7.9	—	—
B		40	26	2 in a jar.	"	7.2	—	—
C		40	38	3 in a jar.	"	6.1	—	—
D		40	16	4 in a jar.	"	5.2	—	—
E		20	14	20 in a jar.	"	3.2	—	—
F		20	17	20 in a jar.	"	2.7	—	—

Experiment 202 shows but one fact, *i.e.*, that the amount of excretion is roughly proportional to the size of the snail.

TABLE XII—EFFECT OF SHELL SALTS.

Ex.	Days.	No. beg.	No. end.	Variable.	Constant.	Av. size.
55A	48	6	7	Control.	W. P. 500 cc.	3.3
B		6	5	Powdered $CaCO_3$.		3.9
C		6	5	Powdered $CaSO_4$.		4.2
D		6	5	Powdered $Ca_3(PO_4)_2$.		3.0
56A	86	7	5	Control.		6.0
B		7	5	$CaCO_3$.		5.7
C		7	6	$CaSO_4$.		6.8
D		7	7	$Ca_3(PO_4)_2$.		6.5
201A	43	4	4	Control.	N. clean jar.	1.9
B		4	3	Sediment.		1.8
C		4	4	$CaSO_4$.		2.0
D		4	2	$CaCO_3$.		1.6
202A	43	4	4	Control.	N. clean jar.	1.3
B		4	4	Sediment.		2.3
C		4	4	$CaCO_4$.		2.2
D		4	4	$CaCO_3$.		2.
203A	38	4	4	Control.	N. Started	1.9
B		4	4	Sediment.	with 3 weeks	2.1
C		4	4	Crushed shells.	growth of algæ.	3.4
204A	38	4	2	Control.	W. P.	3.9
B		4	4	Sediment.		5.9
C		4	3	Crushed shells.		8.0

Effect of Shell Salts.—If it were possible to measure some other physiological process of the snail than growth, another method might be instituted to attack the study of the effect of environment. As it is possible to measure the activity of a certain tissue in the pond snail by the amount of its secretions, a series of experiments were conducted. The tissue referred to is the mantle which secretes the shell. With this in mind a few experiments with calcium carbonate, calcium sulphate, and calcium phosphate. Snails that had been raised in saturated solutions of these salts, which are but slightly soluble in water, were measured; the results are expressed in Table XII. The salts were supplied as the pure chemical or as ground-up *Lymnœa* shell. The results show that calcium sulphate is most beneficial and that the presence of shell salts are favorable to snail growth. Experiments 55–56 did not consider that the sediment of the ground mineral might introduce another factor. Experiments 201–204 consider this factor. The fact that each chemical seems to favor a separate flora introduces another factor which makes these experiments most unsatisfactory.

Number of Individuals.—Semper ('74) and De Varigny ('94) both reported that in two similar jars, one containing one snail and one containing many, the single one grew the larger in every case. This fact was one of Semper's strongest arguments in favor of the presence of an unknown chemical. De Varigny could not explain this result on his exercise theory, so he advanced a psychological theory based on the fact that two snails might annoy each other. He writes: "Mais que peut être cette influence morale dans le monde des Lymnées? Le problème est embarrassant, et je n'ose décide si la présence de deux Lymnées gêne ou ne gêne pas le pérégrinations de la troisième, etc." (p. 187).

The result of the experiments reported in Table VI of the present work confirm the results of the authors who have investigated this factor. Discarding both Semper's and De Varigny's explanation, we must turn to a consideration of those of the later authors. Willem ('96) explained the result as due to aeration, but it seems rather that Vernon's ('03) explanation is more nearly true. Vernon considers that the toxic influence of accumulations of the waste products of metabolism is the cause of the dwarfing, yet increased aeration will insure more rapid oxidation of those waste products and so remove their harmfulness.

From what has been said it will be seen that the chemical composition of the water is a very important factor in the rate of growth of *Lymnœa.* The composition of the water may exert a toxic or a beneficial effect on the growing snail. This has been explained in the case of effect of numbers in various ways, but most reasonably by lack of aeration and of composition of the water. It is probable that those two factors work together.

4. *Temperature.*—Semper ('79) reported that snails chilled were retarded in growth and that growth ceased at 13° C. Walter ('06) found that they became more active in warm water than in cold water. The experiments of Walter ('06) were repeated in the following way: Four large snails 9 mm. and four small snails 1.5 mm. were placed in a glass dish with about 20 cc. of water. Under the dish a piece of cross-section paper was laid, and on another piece of cross-section paper the position of each snail was plotted every five minutes for a period of three hours.

For the first hour the dish was in a cold room and the temperature fell from 12½° to 6½° C. The dish was then packed around with ice for half an hour until the temperature fell from 6½° to 3½° C. The dish was then placed in a warm room for one hour, the temperature rising from 3½° to 17° C. For the next twenty minutes it was placed near a radiator, and the last ten minutes the dish was placed above the radiator, the temperature rising from 17° to 26° C. Fig. 5 shows how the snails were affected. tt represents the temperature curve; the heavy black line the distance in millimeters that the small snails travelled in periods of five minutes; the dotted line indicates the same thing for the large snails.

TABLE XIII.

Temperature.	Speed.		Remarks.
	Large Snails.	Small Snails	
12½°- 8½°	Increase.	Increase.	In cold room.
8½°- 6½°	Decrease.	Decrease.	" " "
6½°- 3½°	Increase.	Constant.	Packed with snow.
3½°-10°	Decrease.	Sl. decrease.	In warm rooms.
10° -17°	Increase.	Increase.	" " "
17° -22°	"	"	Near radiator.
22° -23°	Decrease.	Decrease.	" "
23° -25°	Increase.	Increase.	On radiator.

The average speed for the small snails closely follows that for the large ones. The table shows several things: (1) that cold applied rather suddenly stimulates the snail to become active so as to escape from the cold. The same reaction is noticed when heat above the optimum is applied. (2) When the water continued cold the activities decreased.

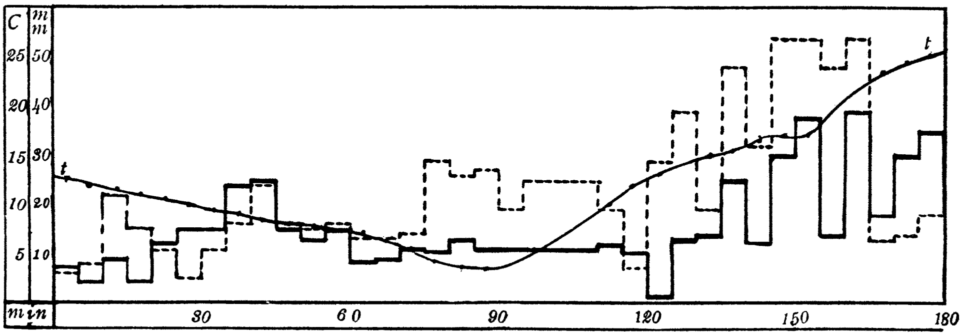

Fig. 5.—Temperature and velocity curve of large and small Lymnæa. [Line t t represents temperature in centigrade during three hours. Dotted line represents distance traveled in m.m. in five-minute intervals by the large snails. The solid line shows the same thing for the small ones.]

The experiments on growth conducted by Semper did not take into account the effect of cold on the water plant. To eliminate this factor the writer alternated the jars with the water plant from the warm to the cold at stated intervals, but transferred the snails from one jar to the other, so that certain snails remained in the warm and certain snails remained in the cold all the time, yet the jars that contained them were the same, and therefore the amount and condition of the food was similar.

The manner that cold acts on the growth of *Lymnæa* may be twofold. Cold, as is so well known, retards the rate of chemical combinations and so retards physiological processes. As growth is a physiological process it is retarded, and as the activities of the animal are physiological processes they are also retarded. Growth depends largely on the presence of food, yet the food of *Lymnæa* is acquired only through constant motion, so it might easily become dwarfed, with abundance of food about it, if conditions should make the snail sluggish. In *Lymnæa* we have seen that both these factors may be at work, reduced physiological processes acting directly on growth, or reduced activities may actually cause dwarfing by lack of food.

TABLE XIV—EFFECT OF HEAT AND COLD.

Ex.	Days.	No. beg.	No. end.	Variable.	Constant.	Size.	Dif.	Per cent.
26A	52	4	4	Warm.	N. 500 cc.	.0055	.0047	49%
B		4	2	Cold.		.0008	—	—
27A	52	4	3	Warm.	W. P. 500 cc.	.0035	.0030	45%
B		4	2	Cold.		.0005	—	—
28A	61	10	8	Warm.	W. P. 500 cc.	.0079	—	—
B		10	10	Cold.		.0080	.0001	0%
91A	52	2	2	Warm.	N. 500 cc.	4.5	2.9	64%
B		2	2	Refrigerator.		1.6	—	—
92A	52	2	2	Warm.	N. 500 cc.	5.6	3.9	70%
B		2	2	Refrigerator.		1.7	—	—
93A	45	1	1	Warm.	N. 500 cc.	8.2	6.0	73%
B		1	1	Refrigerator.		2.2	—	—
147A	48	2	2	Warm.	N. 500 cc.	6.5	3.5	54%
B		2	2	Cold.		3.0	—	—
148A	48	2	2	Warm.	N. 500 cc.	5.2	2.6	50%
B		2	2	Cold.		2.6	—	—
205A	42	3	2	Warm.	W. P. 750 cc.	4.8	1.2	25%
B		3	2	Cold.		3.6	—	—
206A	42	4	4	Warm.	W. P. 750 cc.	7.2	4.9	68%
B		4	3	Cold.		2.3	—	—
207A	44	5	4	Warm.	W. P. 750 cc.	7.6	4.6	60%
B		5	3	Cold.		3.0	—	—
208A	44	5	4	Warm.	W. P. 750 cc.	8.0	5.4	67%
B		5	3	Cold.		2.6	—	—

5. *Light.*—Beginning with Higgenbottom ('50), various writers have conducted experiments on the effect of light on the growth of animals. The work of these authors, including Yung ('78, '80 and '92), Vernon ('95), Warren ('00) and Beclard ('58), deals largely with the effect of colored light on the development of different animals. The present work considers the effect of light and darkness alone. Although experiments were attempted with colored lights, yet the many difficulties in the shape of uncontrollable factors made the results so unreliable that space will not be taken in discussing them. Even in the experiments on light and darkness the factor of food was with difficulty controlled. It was only by resorting to similar means as in the experiments on temperature that this factor was controlled at all. However, this did not remove all the uncontrolled factors present. There was also the chance of there being a different temperature of the water between the two jars; this difference at times amounting to 2° C.

Although the experiments of Walter ('06) and some of the writers seem to indicate that *Lymnæa* is slightly negatively phototactic, yet darkness is prejudicial to growth (Table XV).

Table XV—Effect of Light and Dark.

Ex.	Days.	No. beg.	No. end.	Variable.	Constant.	Size.	Dif.	Per cent.
57A	54	6	4	Light.	N. 500 cc.	4.9	3.2	65%
B		6	4	Dark.	"	1.7	—	—
58A	54	6	5	Light.	W. P. 500 cc.	3.0	1.8	60%
B		6	4	Dark.	"	1.2	—	—
59A	42	5	5	Light.	W. P. 500 cc.	8.5	2.1	25%
B		5	5	Dark.	"	6.4	—	—
103A	47	4	3	Light.	N. 750 cc.	3.0	1.8	60%
B		4	1	Dark.	"	1.2	—	—
104A	45	5	3	Light.	N. 750 cc.	2.5	1.0	40%
B		5	1	Dark.	"	1.5	—	—
105A	45	5	3	Light.	N. 750 cc.	2.5	.8	32%
B		5	5	Dark.	"	1.7	—	—

This factor of light is of less importance than the other external conditions affecting growth, and is one that the snail can directly control to some extent through its behavior, and is also one that can be easily regulated in the laboratory. It is almost impossible to devise experiments on the effect of light on animals whose food consists of green plants, and experiments so conducted can have little significance.

6. *Area.*—According to De Varigny's exercise theory, dwarfing of *Lymnæa* was caused by too little area for the snail to crawl upon. To test the truth of this hypothesis, structures of various shapes were constructed out of microscopic slides and introduced into one of two similar jars containing snails. As some of the structures were cemented with sealing wax, sealing wax was added to the other jar of the experiment, so that there was no difference between the jars, except the fact that one had a larger surface exposed on which the snail could crawl than did the other. The results (Table XVI) were contrary to what might have been expected from De Varigny's hypothesis. It can hardly be that the slides hindered the snails from wandering around; on the contrary the great area exposed would form a surface on which much more algæ would grow.

TABLE XVI.

Ex.	Days.	No. beg.	No. end.	Variable.	Constant.	Size.	Dif.	Per cent.
65A	28	1	1	Area = 125 sq. c.	N. 200 cc.	2.	—	—
B		1	1	Area = 40 sq. c.		4.3	2.3	53%
66A	28	1	1	Area = 125 sq. c.	N. 200 cc.	4.	—	—
B		1	1	Area = 40 sq. c.		6.	2.0	33%
67A	48	1	1	Area = 165 sq. c.	N. 400 cc.	9.	—	—
B		1	1	Area = 80 sq. c.		9.5	.5	5%
68A	48	1	1	Area = 165 sq. c.	N. 400 cc.	9.	—	—
B		1	1	Area = 80 sq. c.		9.5	.5	5%
69A	48	6	5	Area = 455 sq. c.	N. 500 cc.	3.2	—	—
B		6	6	Area = 285 sq. c.		4.3	1.1	25%
70A	48	6	6	Area = 455 sq. c.	W. P. 500 cc.	3.9	.2	5%
B		6	6	Area = 285 sq. c.		3.7	—	—
71A	28	2	1	Area = 455 sq. c.	W. P. 500 cc.	4.5	.1	2%
B		2	2	Area = 285 sq. c.		4.4	—	—
72A	28	2	2	Area = 455 sq. c.	W. P. 500 cc.	5.	.9	18%
B		2	1	Arta = 285 sq. c.		4.1	—	—
73A	69	7	7	Area = large.	N.	3.3	—	—
B		7	7	Area = small.		4.6	1.3	30%
74A	69	7	7	Area = large.	W. P.	2.8	—	—
B		7	6	Area = small.		4.1	1.3	31%
75A	29	2	1	Area = large.	W. P.	4.	—	—
B		2	1	Area = small.		4.7	.7	15%
106A	58	2	2	Area = 314 sq. c.	N. 500 cc.	4.7	.2	4%
B		2	2	Area = 42 sq. c.		4.5	—	—
107A	58	2	2	Area = 144 sq. c.	N. 500 cc.	4.4	—	—
B		2	1	Area = 42 sq. c.		8.	3.6	45%
108A	51	3	3	Area = 144 sq. c.	N. 500 cc.	4.5	.4	8%
B		3	3	Area = 42 sq. c.		4.1	—	—
109A	50	2	2	Area large.	N. 500 cc.	2.0	—	—
B		2	2	Area small.		4.6	2.6	56%
110A	50	3	3	Area large.	N. 500 cc.	2.8	—	—
B		3	1	Area small.		5.0	2.2	44%
111A	35	2	2	Area large.	N. 500 cc.	4.2	—	—
B		2	2	Area small.		4.7	.5	10%
112A	35	2	2	Area large.	N. 500 cc.	1.7	—	—
B		2	2	Area small.		2.9	1.2	41%

This experiment suggests some results reported by Dandino ('04) on the effect of toxic solutions on germinating peas and corn. In toxic solutions (dilute acids) the addition of quartz sand (washed in HCl and distilled water) was 32 times as toxic as that without the sand. The author explains this fact as the result of surface action. In the present work experiments with quartz sand and even with pebbles caused an increase in the rate of growth. This is an effect opposite to that found by Dandino, yet it throws very little light on the bad effects caused by the presence of microscopic slides.

As De Varigny used flat dishes in contrast to spherical flasks, his cases of dwarfing by rearing in a small area can be referred with very little doubt to lack of aeration.

7. *Volume.*—Before the preceding series of experiments were completed, so before the bad effect of the presence of microscopic slides was known in experiments with volume, the inside area of the two similar jars was made equal by a structure of slides of calculated area. The amount of water in the two jars was not the same, the smaller volume of water containing the structure of slides. Experiments without the structure were later tried, but all the experiments led to the same result (Table XVII): the snails in the smaller volume were the smaller.

TABLE XVII—EFFECT OF VOLUME.

Ex.	Days.	No. beg.	No. end.	Variable.	Constant.	Size.	Dif.	Per cent.
76A	57	6	6	Volume small.	N.	3.2	—	—
B		6	6	Volume large.		4.3	1.1	28%
77A	57	6	5	Volume small.	W. P.	3.3	—	—
B		6	6	Volume large.		3.7	.4	17%
78A	53	1	1	Volume small.		5.0	—	—
B		1	1	Volume large.		6.5	1.5	23%
79A	42	1	1	Volume small.		5.2	—	—
B		1	1	Volume large.		7.0	1.8	26%
80A	42	1	1	Volume small.		6.0	—	—
B		1	1	Volume large.		6.0	—	—
81A	69	7	3	Volume small.	N.	2.8	—	—
B		7	4	Volume large.		3.5	.7	20%
82A	69	7	9	Volume small.	W. P.	3.4	—	—
B		7	3	Volume large.		5.5	2.1	38%
113A	58	2	2	220 cc.	N.	3.0	—	—
B		2	2	500 cc.		4.5	1.5	33%
114A	58	2	1	220 cc.	N.	3.8	—	—
B		2	1	500 cc.		8.0	4.2	52%
115A	51	3	3	220 cc.	N.	3.2	—	—
B		3	3	500 cc.		4.1	.9	22%
116A	50	3	3	220 cc.	N.	2.8	—	—
B		3	2	500 cc.		4.6	1.8	40%
117A	35	2	2	220 cc.		1.7	—	—
B		2	2	500 cc.		4.7	3.0	63%

Dandino, referred to above, found that in toxic solutions, *i.e.*, weak acids, the radicles of peas and corn grew longer in a small volume than in a larger volume. This could be explained by assuming that there is but a definite amount of toxin present to act on the seed. With the snail, however, the case is reversed. The toxin, which we have shown in the preceding sections to be present, is ever being increased in quantity by the secretions of the animal. In the case of the seedling the solution becomes weaker and weaker.

Pearl and Dunbar ('05) found that *Paramecium* in small vessels were dwarfed. This is due most likely to the accumulation of excreted matter. In fact almost every case of this kind among aquatic animals can be so explained.

8. *Alternation of Conditions.*—In connection with some of the experiments on heat and cold, a jar was moved from the warm to the cold, and *vice versa,* at two weekly intervals for a period of two months, with the very striking result that the alternated snails were larger at the end of that time than those kept in the warm all of the time. This result was accomplished notwithstanding the fact that, when in the cold, the water in the alternate jars was sometimes frozen. This experiment led to a series of experiments in the same line, and although many were as striking as the first, yet the larger snails were those, as a general rule, that had been in the warm room all the time. This control in the warm room was every two weeks transferred to a jar from the cold conditions, while at the same time the jar in which they had been living was placed in the cold and snails that had lived in the cold all the time added. This process of changing the snails was performed every two weeks or every week. The interval of alternation is given in the tables. See Tables VIII–XX. Not only were alternate conditions of heat and cold considered, but also alternating conditions of starving and feeding and light and dark. The latter experiments are not of particular interest, as the alternated snails are purely intermediate in size between those under favorable and those under unfavorable conditions. The starving and feeding experiments, however, closely approximated those of heat and cold. Some were larger and some were smaller than the control. These results must mean that the change from an unfavorable to a favorable condition causes the snail to grow faster than if it were continually in the favorable condition.

9. *Experiments on Tadpoles.*—As Yung ('85) performed some experiments on the effect of external conditions on tadpoles, arriving at the same conclusion as did Willem ('96), *i.e.*, that dwarfing was caused by lack of aeration, the writer, using the methods described in the preceding pages, repeated these experiments with tadpoles of *Rana* in the spring of 1907.

TABLE XVIII—ALTERNATE HEAT AND COLD.

Ex.	Days.	No. beg.	No. end.	Variable.	Constant.	Size.	Dif.	Per cent.
149A	52	4	1	Alt. 2 weeks.	N. 500 cc.	.0110	.0055	23%
B		4	4	Warm.		.0055	—	—
150A	52	4	4	Alt. 2 weeks.	W. P. 500 cc.	.0078	.0043	23%
B		4	3	Warm.		.0035	—	—
151A	61	10	10	Alt. 2 weeks.	W. P. 500 cc.	.0086	.0024	10%
B		10	7	Warm.		.0062	—	
152A	52	2	2	Alt. 1 week.	N. 500 cc.	4.4	—	—
B		2	2	Warm.		4.5	.1	.02%
153A	52	2	2	Alt. 1 week.	N. 500 cc.	4.9	—	—
B		2	2	Warm.		5.6	.7	12%
154A	45	1	1	Alt. 1 week.	N. 500 cc.	6.0	—	—
B		1	1	Warm.		8.5	2.5	29%
155A	42	8	5	Alt. 1 week.	W. P. 750 cc.	5.0	—	—
B		8	7	Warm.		5.9	.9	15%
156A	42	8	4	Alt. 2 weeks.	W. P. 750 cc.	5.6	—	—
B		8	4	Warm.		6.5	.9	14%
157A	42	9	8	Alt. 2 weeks.	W. P. 750 cc.	3.5	.4	11%
B		9	8	Warm.		3.1	—	—
158A	48	2	2	Alt. 1 week.	N. 500 cc.	3.0	—	—
B		2	2	Warm.		6.5	3.5	54%
159A	48	2	2	Alt. 1 week.	N. 500 cc.	3.1	—	—
B		2	2	Warm.		5.2	2.1	40%
209A	42	3	3	Alt. 1 week.	W. P. 750 cc.	10.2	5.8	57%
B		3	2	Warm.		4.4	—	—
210A	42	4	4	Alt. 2 weeks.	W. P. 750 cc.	6.3	—	—
B		4	4	Warm.		7.2	.9	12%
211A	44	5	5	Alt. 2 weeks.	W. P. 750 cc.	6.1	—	—
B		5	5	Alt. 2 weeks.		4.2	—	—
C		5	4	Heat.		7.6	2.5	34%
212A	44	5	5	Alt. 1 week.	W. P. 750 cc.	6.6	—	—
B		5	5	Alt 1 week.		6.7	—	—
C		5	4	Heat.		8.0	1.4	18%

TABLE XIX—ALTERNATE LIGHT AND DARK.

Ex.	Days.	No. beg.	No. end.	Variable.	Constant.	Size.	Dif.	Per cent.
182A	54	6	5	Alternate.	N. 500 cc.	1.7	—	—
B		6	4	Light.		4.9	3.2	65%
183A	54	6	5	Alternate.	W. P. 500 cc.	1.7	—	—
B		6	5	Light.		3.0	1.3	43%
184A	47	4	2	Alternate.	N. 750 cc.	1.4	—	—
B		4	3	Light.		3.0	1.6	53%
185A	45	5	2	Alternate.	N. 750 cc.	1.9	—	—
B		5	3	Light.		2.5	.6	24%
186A	45	5	5	Alternate.	N. 750 cc.	1.8	—	—
B		5	3	Light.		2.5	.7	28%

TABLE XX—ALTERNATE STARVING AND FEEDING.

Ex.	Days.	No beg.	No. end.	Variable.	Constant.	Size.	Dif.	Per cent.
160A	52	2	2	Alt. 1 week.	N. 500 cc.	4.7	.2	4%
B		2	2	Control.		4.5	—	—
161A	59	2	2	Alt. 1 week.	N. 500 cc.	5.8	.1	2%
B		2	2	Control.		5.7	—	—
187A	38	5	4	Alt. 2 weeks.	N. 500 cc.	2.6	—	—
B		5	4	Control.		3.3	.7	21%
188A	38	2	1	Alt. 2 weeks.	N. 500 cc.	3.8	—	—
B		2	1	Control.		4.0	.2	5%
189A	34	3	2	Alt 2 weeks.	N. 500 cc.	2.7	—	—
B		3	3	Control.		5.0	2.3	46%
190A	34	3	3	Alt. 2 weeks.	N. 500 cc.	2.8	—	—
B		3	3	Control.		4.3	1.5	35%
191A	31	4	3	Alt. 2 weeks.	W. P. 500 cc.	3.3	—	—
B		4	4	Control.		4.2	.9	21%
192A	31	4	4	Alt. 2 weeks.	W. P. 500 cc.	2.9	—	—
·B		4	4	Control.		6.4	3.5	55%

The results—which may be classed as follows: effect of artificial aeration, of surface aeration, of volume, of number of individuals—were exactly the same as those found for *Lymnæa.*

VI. EFFECT OF EXTERNAL CONDITIONS ON THE NUMBER OF EGGS LAID.

To supplement the experiments on the effect of external conditions on growth, and to observe the effect of external conditions on some physiological process rather different from growth, the following series of experiments was arranged. When adult *Lymnæa* is brought into the warm laboratory in the late winter or early spring it lays an immense number of fertile eggs. This fact was made the basis of some experiments. Snails gathered at such a time were placed under various conditions and the number of eggs laid during a given time recorded. Conditions that one would not consider to have any effect whatever on fertility were quite effective in their results.

1. *Sediment.*—As we have seen on p. 424, the presence of sediment is beneficial to snail growth, yet the presence of sediment is also of advantage in increasing the fertility of the snail.

Four adult snails were isolated in four jars with a small amount of sediment, and four jars were similarly treated without the sediment. At the end of some days the eggs in each jar were counted. See Table XXI.

TABLE XXI.

Ex.	No begin.	No. end.	Variable.	No. of eggs laid.	
A...........	1	1	Sediment.	39	
B...........	1	1	"	48	
C...........	1	1	"	13	
D...........	1	1	"	62	
				—	162
E...........	1	1	None	10	
F...........	1	1	"	15	
G...........	1	1	"	15	
H...........	1	1	"	18	
				—	58

The total of 162 in favor of the sediment is quite striking, against the total of 58 eggs without sediment, yet the small number of snails in the experiment must not be overlooked. As the writer did not have a chance to repeat this experiment its value is only suggestive.

2. *Number of Individuals.*—In each of seven jars with *Ceratophyllum* was placed a single snail. In seven other jars similarly arranged were placed two snails each. In ten days the seven snails in seven jars laid 1,149 eggs. The fourteen snails in seven jars laid 1,277 eggs.

The result of this experiment is similar to the growth experiment. In other words two snails in a jar together do not lay twice as many eggs as a single individual, but each snail lays only half as many eggs as when it is alone in the jar. Thus again is illustrated the bad effect of the presence of the waste products of metabolism in the water.

3. *Effect of Light.*—In each of twelve similar jars one snail was placed and *Ceratophyllum* was added to each jar. Six jars were placed

TABLE XXII.

In Light.			In Dark.		
Size of snail	No of egg cases.	No. of eggs laid in 8 days.	Size of snail.	No. of egg capsules.	No. of eggs laid in 8 days.
	7	117		4	61
	6	173		8	114
	7	184		4	59
	5	190		2	56
	6	136		4	155
	—	—		—	—
	31	800		22	445

in diffused daylight and six in the dark. During the daytime the jar in the light had the temperature about two degrees higher than those in the dark. As the snails were of slightly different sizes, all the jars were placed in a row with the snails in series from the largest to the smallest. Every other jar was then put in the dark. The experiment ran 8 days. In the following table the number of egg capsules laid and the total number of eggs per individual is indicated. One snail died in the dark and one died in the light. Both are left out of account in the table.

It will be seen that those in the light laid nearly twice as many eggs as in the dark.

5. *Other Effects and Observations.*—Snails brought into the laboratory from the ponds lay at first a great number of eggs in a single egg case, and the masses laid subsequently contain fewer and fewer eggs. (See Table XXIII.) Placing two individuals together does not have an effect of revivifying the fertility of the snail, but has the opposite effect.

TABLE XXIII.

Experiment.	No. snails.	Days ran.	Egg Case.													
			1st	2d	3d	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th
A	1	10	36	28	20	29	31	16	25	19						
B			83	38	16	25	33	9	1							
C			85	38	20											
D			43	39	15	5										
E			89	38	25	25	13	12	10	7	23					
F			48	34	28	26	16	17								
G			37	36	19	3	17									
A	1	11	40	16	12	8	5									
B			52	36	16	15	13	19	20	12	14	17	8			
C			40	16	8	4	3	6								
D			52	29	19	11	9									
E			29	27	19	18	13	9	5	5						
F			88	37	21	22	13	12	9	9	9	14	7	15	8	16
G			52	13	11	8	16	14	9	5	10					
H			35	19	15	9	12									

Table showing the number of eggs in successively laid egg cases after the snail is brought into a warm room from out of doors in the winter time.

The last eggs laid by these snails are sometimes quite abnormal. Sometimes the eggs are fused, sometimes there is a capsule or a number of small capsules without a single egg.

Some snails prefer to lay their eggs on the water plant, others always lay their eggs on the glass jar, while still others show no preference at all.

VII. Summary of the Conclusions.

1. The effect of *Myriophyllum* and of *Elodea* on the growth of *Lymnæa* is quite complex. That it is not a simple factor that is being dealt with is indicated by the inconstancy of the results of the experiments. Notwithstanding the fact that one factor has been isolated, yet it is probable that there are other factors besides. This determined factor is the presence or absence of sand in the so-called "gizzard." In the latter case plant tissue, although ingested cannot be assimilated, so that the snail is smaller because it actually lacks food. On the other hand it is possible that the products of plant metabolism may have a harmful effect on the growing snail.
2. The accumulations of fæcal matter of *Lymnæa,* instead of having the harmful effect on growth as described by De Varigny ('94), when washed and filtered, have a beneficial effect. These tangled masses of unassimilated food form a great harbor for algæ, and so increase the food supply of the snail.
3. The "original planting" of the aquarium, *i.e.*, algæ accidentally introduced with the water, causes great variation in the size of the snails.
4. Experiments on artificial aeration confirm the conclusions of Yung and Willem; yet experiments on surface aeration do not seem so clear.
5. Vernon reported that Echinoderm larvæ raised in solutions in which other larvæ had been raised were dwarfed. De Varigny found the same thing true for *Lymnæa.* Experiments on *Lymnæa columella* confirm the results of the two authors referred to. Weak solutions were found beneficial and concentrated solutions harmful. Experiments using urea gave the same result. Why dilute solutions of excreted matter and urea are beneficial and concentrated solutions are harmful may be explained in the following way. The presence of the excretions which contain plant food may cause more algæ, snail food, to grow; on the other hand the solutions are harmful to snail growth. In dilute solutions, however, the quantity of toxic substance may be so little harmful that an increase of food will overbalance the harmful effect. However, this explanation is not very satisfactory as the Echinoderm larva experimented on by Vernon had no mouth and so did not eat.
6. As Semper and De Varigny showed, the number of individuals in

a jar affect the rate of growth. The cause is probably due to increased secretions and perhaps to diminished aeration.

7. Calcium salts in the water seem on the whole beneficial to growth —calcium sulphate particularly so.

8. Growth of *Lymnæa* is inhibited by cold, as Semper reported. This factor may act in two ways—directly on the physiological processes of the animal and indirectly through the inability to procure food, the snail becoming too sluggish to search for it.

9. Area. The cause that De Varigny advanced to explain dwarfing was lack of exercise on the part of the snail. The greater the place to crawl, the greater the snail. However, when aeration was kept constant, which De Varigny failed to do, the results were not significant.

10. Volume. That the volume of the medium affects the growth of *Lymnæa* is certain. Willem explains the fact on the ground of aeration. The author accepts this view, but considers that the more concentrated excretions in smaller volumes must play an equal part.

11. Alternate Conditions. Snails under unfavorable conditions when placed under favorable ones grow faster than if they were continuously in favorable conditions. It would seem that the change from unfavorable to favorable conditions of life acts as a stimulant for growth. However, this does not always mean that it surpasses the control size. It rarely does that.

12. Not only does the environment affect growth, but it affects the number of eggs laid in a given time. This fact is very important, because it shows that the environment probably affects all the physiological processes and not one alone.

13. This study reveals the fact that confinement influences the growth of aquatic animals in three ways—through the amount of food, through the amount of oxygen and through the accumulations of the waste products of metabolism. The phenomenon is not a simple one and each factor plays its own part.

Literature Referred to.

Bessey, C. E. 1892. Botany, 7th edition.

Brockmeier, H. 1898. Süsswasserschnecken als Planktonfischer. Forch-Ber. Biol. Sta. Plon., Th. VI, p. 165.

Clowes, F., and Coleman, J. B. 1903. Quantitative Chemical Analysis, p. 323.

Cooke, A. H. 1895. Cambridge Natural History, Mollusks, pp. 94–95.

Cuvier. 1817. Mémoire sur le Limnée et le Planorbe.

Dandino, J. B. 1904. Relation of Mass Action and Physical Affinity to Toxicity, with Incidental Discussions as to how far Electrolytic Dissociation may be Involved. Am. Jour. Sci., Vol. XVII, 4th series, p. 437.

Davenport, C. B. 1899. Experimental Morphology, Vol. II, pp. 473–478.

FOREL. 1874. Materiaux pour servir à l'étude de la faune profonde du lac Léman. Bull. Soc. Vaud. Sci. Nat., t. XII, p. 72.

——. 1904. La Léman, p. 103.

HYATT, A. 1880. Changes in the Shell of Lymnæa megasoma produced by Confinement. Am. Nat., Vol. XIV, p. 51.

HOGG, J. 1854. Observations on the Development and Growth of the Water Snail Lymnæus stagnalis. Quar. Jour. Mic. Sci., Vol. II, p. 91.

MOQUIN-TANDON. 1855. Histoire Naturelle des Mollusques terrestres et fluviatiles de France, Paris, t. I, p. 81.

PEARL, R., and DUNBAR, F. J. Some Results of a Study of Variation in Para mecium. Mich. Acad. of Sci., 7th Ann. Rep.

RATHAY, E. 1898. Ueber den Frass von Helix hortensis auf Baumrinden. Zeit f. Pfanzenkr., Bd. VIII, p. 129.

SACHS, J. 1875. A Text-book of Botany, Oxford, Eng. trans., p. 621.

SEMPER, C. 1874. Ueber die Wachsthums-Bedingungen des Lymnæus stagnalis. Arb. Zool.-Zoot. Inst., Wurzburg, Bd. I, pp. 138–167.

——. 1879. Animal Life. International Scientific Series, pp. 160–167.

STERKI, V. 1895. Food of the Limnæidæ. Nautilus, Vol. V, p. 94.

DE VARIGNY, H. 1892. Experimental Evolution. Nature Series, pp. 79–88.

——. 1894. Recherches sur le nanisme expérimental. Contribution a l'étude de l'influence du milieu sur les organismes. Jour. Anat. et Phys., Paris, t. XXX, pp. 147–188.

——. 1895. Note sur le period de croissance chez Lymnæa stagnalis. Bull. Mus. Hist. Nat., Paris, t. I, pp. 131–132.

VERNON, H. M. 1895. Effects of Environment on the Development of Echinoderm Larvæ. Phil. Trans. Roy. Soc. London, Vol. CLXXXVI, pp. 577–632.

——. 1899. The Relations between Animal and Vegetable Life. Mitth. aus der Zool. Sta. zu Neapel, Bd. XIII, p. 334.

——. 1903. Variation in Animals and Plants. Int. Nat. Sci. Series.

WALTER, H. E. 1906. Behavior of the Pond Snail Lymnæus elodes. Cold Spring Harbor Monographs, VI.

WARREN. 1900. Changes in Environment of Daphnia. Quar. Jour. of Mic. Sci., Vol. XLIII, p. 212.

WHITFIELD. 1882. Description of Lymnæa megasoma Say, with an Account of Changes produced in the Offspring by Unfavorable Conditions of Life. Bull. Am. Mus. Nat. Hist., Vol I, p. 29.

WILLEM, V. 1896. Observations sur la respiration cutanée des Lymnées et son influence sur leur croissance. Bull. de l'Acad. Roy. des Sci. Brussels, t. XXXII, p. 566.

YUNG, E. 1878. Contributions à l'histoire de l'influence des milieux physiques sur les êtres vivants. Arch. Zool. Exper. et Gen., t. VII, pp. 251–282.

——. 1880. De l'influence des lumieres colorées sur le developpement des animaux. Mitth. a. d. Zool. Stat. zu Neapel, Bd. II, pp. 233–237.

——. 1885. De l'influence des variations du milieu physico-chemique sur le developpement des animaux. Arch. des Sci. Phys. et Nat., t. XIV, pp. 502–522.

——. 1888. Contributions à l'histoire physiologique de l'escargot (Helix pomatia). Mem. Cour., t. XLIX, p. 119.

——. 1892. Comp. Rend., CXV, pp. 620, 621, October 24.